

ICTTP 2014

## Integrating spatial information across time

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### Abstract

A series of experiments have examined whether spatial information (i.e., location of objects within a room) that is encoded at different points in time is readily integrated into a single mental representation during learning or whether the time of encoding is used to distinguish information and keep them in distinct representations. Overall, our findings support the idea that when encoding locations people weigh probabilistically all available cues, including temporal, to structure their spatial memories.

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Selection and peer-review under responsibility of the Organizing Committee of the International Conference on Timing and Time Perception.

**Keywords:** Spatial memory; Temporal cues; Perspective-taking

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### 1. Spatial representations

Much of our everyday activity relies on the availability of spatial memories coding information about the locations of objects in our environment. For example, deciding on a route ahead of driving in a city entails having stored information about how city features, such as streets and landmarks, are laid out relative to each other. Research in spatial cognition documents that people have no difficulty creating and maintaining such spatial representations even for locations encoded at different points in time (e.g., landmarks in a foreign city encountered sequentially during the exploration, furniture in a house viewed while moving from one room to the other).

A well-known finding from research in this field is that spatial representations are organized hierarchically (e.g., Hirtle & Jonides, 1985). For example, we may remember our city by parsing it into neighborhoods and maintaining the spatial relations of landmarks within each neighborhood as a distinct representation. A higher-order representation could then connect these representations allowing people to compute spatial relations across

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neighborhoods. Similarly, our spatial memory about a house may consist of individual spatial representations for each room and a higher order representation describing the spatial relations among the rooms. If people readily group locations to form various representations, the question that arises is what information they rely on to do so. Previous research has documented that spatial factors such as the relative distance of locations (e.g., Ishikawa & Montello, 2006) and perceptual factors such as the color and the shape of objects (e.g., Hommel, Gehrke, & Knuf, 2000) can serve as grouping principles.

## **2. Studies on integration: The general paradigm**

We have recently set out to investigate whether the time at which the encoding takes place can be used as a cue for grouping locations in spatial representations. The idea is that if people maintain temporal information about their experiences with objects then this information may be used to group their locations (i.e., objects perceived with close temporal proximity are stored in the same representation). Unfortunately, in previous research spatial and temporal distance were confounded.

In the typical paradigm we have used across several studies, participants encode locations in memory by studying sequentially two different layouts of objects occupying the same general space around them. Following the learning phase, participants respond to a series of perspective-taking trials by pointing. Trials require that participants imagine facing one of the memorized objects and point from that imagined perspective towards a second object. Pointing error (i.e., the angular deviation of the produced pointing response from the correct response) and pointing latency are recorded and analyzed. Importantly, trials vary as to whether they involve two objects from the same layout or two objects from different layouts. By comparing pointing error and latency for within and between-layout trials and determining whether switching costs are present we can infer whether participants maintained a distinct representation for each of the studied layouts or whether they integrated all locations into a single representation during learning.

## **3. Findings and conclusions**

In one study we conducted with immersive virtual environments (Adamou, Avraamides, & Kelly, 2013) participants studied layouts with objects that were placed around them in a round (Experiment 1) or a square (Experiment 2) room and were later tested with perspective-taking pointing trials. Results from Exp. 1 showed substantial switching costs in both error and latency suggesting that participants maintained separate representations for each layout. This conclusion is further corroborated by the finding that performance for within-layout trials was best when participants adopted in imagery the perspective from which each layout was studied (i.e., participants maintained separate viewpoint-dependent representations). In contrast, results from Exp. 2 indicated that the stable environmental reference frame provided by the square room caused many, but not all, participants to integrate the locations from the two layouts within a common representation. Participants who integrated performed equally well for within- and between-layout judgments, and also represented both layouts using a common reference frame. Further experiments have verified that switching costs remained even when two layouts are studied from the same perspective (see also Giudice, Klatzky, & Loomis, 2009).

More recent experiments with information-rich environments (which provide alternative organizing cues) have shown switching costs in accuracy but not in latency (Pantelidou & Avraamides, *in preparation*). Our working hypothesis is that although temporal information can be used as an organizing principle for separating object locations across representations in memory, it is easily overridden by the presence of other cues that facilitate integration (see also Avraamides, Adamou, Galati, & Kelly, 2010; Greenauer, Mello, Kelly, & Avraamides, 2013).

Overall our findings are consistent with the idea that when encoding locations in memory people weigh probabilistically all available cues, including non-spatial ones, to structure their memories (Galati & Avraamides, 2013; Galati et al., 2013).

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